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DERIVATION OF THE VENTILATION RECIRCULATION EQUATIONS RELEVANT TO UNDERGROUND DIESELIZED MINES

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ABSTRACT

Canadian mines operate with the additional considerable expense of mine air heating, usually by propane heaters, during the winter season, to make a suitable workplace. Recirculation of the already heated, used mine air would significantly reduce this expenditure. This can be easily accomplished when the exhaust air and intake air shafts are located in close proximity to one another. The vertical shafts can then be linked with a horizontal heading in which a fan and control equipment can be installed to effect the required recirculation flow.

However, in dieselized workings this means that the recirculated air would contain a level of pollutants. The amount of recirculated air permissible would then depend on the acceptability of the quality of the resulting mix with fresh air that is then directed to the workplace.

The following derives expressions relating to recirculating flow in these circumstances, using the CANMET Air Quality Index (AQI) as the criterion for air quality acceptability.

KEYWORDS: diesel, ventilation, recirculation.

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DÉRIVATION DES ÉQUATIONS RELATIVES À LA RECIRCULATION DE L'AIR DANS LES MINES SOUTERRAINES DIÉSÉLISÉES

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RÉSUMÉ

Pendant la saison froide, le réchauffage de l'air dans les installations minières canadiennes (habituellement au moyen de réchauffeurs au propane), représente une source additionnelle de dépenses. La recirculation de l'air déjà réchauffé réduirait considérablement les dépenses. Il est facile de faire recirculer l'air quand l'aspirateur d'air et la prise d'air sont situés à proximité l'un de l'autre. Les conduits d'air verticaux peuvent être reliés à une voie d'air horizontale dans laquelle on peut installer un éventail et un appareillage de contrôle en vue d'assurer la recirculation de l'air.

Toutefois, dans les installations minières diésélisées, l'air est susceptible de contenir une certaine quantité de polluants. Le volume acceptable d'air recirculé dépendrait alors de la qualité du mélange d'air recirculé et d'air pur qui serait acheminé vers le lieu de travail.

Dans le présent rapport, les auteurs utilisent des termes se rapportant à la recirculation de l'air ainsi que l'Indice de contrôle de la qualité de l'air (IQA) développé par CANMET, comme critère d'acceptabilité.

Mots-clé : diesel, ventilation (aérage), recirculation.

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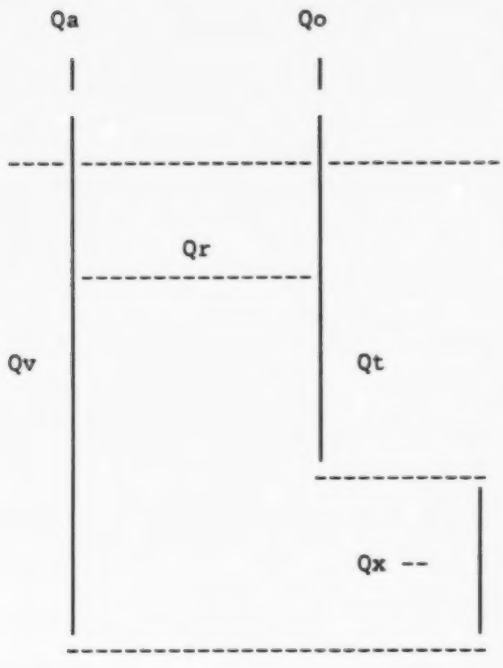
RECIRCULATION EQUATION DERIVATION

Figure 1 is a schematic of a dieselized mine having the characteristics described briefly above. A CO_2 balance in workings where a diesel-powered mining machine(s) operates, can be expressed using the symbols defined as follows:



Qa - fresh intake air
Qv - ventilation air to working
Qr - recirculated used air
Qx - exhaust flow from diesel engine
Qt - total flow from workings
Qo - outlet air

The dimensions of the above flows are in cfm, and the subscripts are used to define the locations of the gas concentrations, for example:

CO_2a - % carbon dioxide in inlet air
COx - carbon monoxide in ppm in undiluted diesel exhaust gas
NOv - nitric oxide in ppm in ventilation to workings
NO_2o - nitrogen dioxide in ppm in outlet air
SO_2r - sulphur dioxide in ppm in recirculation flow
RCDt - respirable combustible dust in mg/m^3 in total flow

Fig. 1 - Ventilation system schematic

Using these symbols and units, the CO_2 balance is derived as follows:

$$Qa.CO_2a + Qr.CO_2r + Qx.CO_2x = Qt.CO_2t$$

because $CO_2r = CO_2t = CO_2o$ and $Qt = Qv + Qx$ and $Qr = B.Qv$,

where B is the (% recirculation flow/100)

then $Qa.CO_2a + Qx.CO_2x = CO_2o\ (Qt - Qr)$

$= CO_2o\ (Qv + Qx - Qr)$

$= CO_2o\ (Qv + Qx - B.Qv)$

Therefore $$CO_2o = \frac{Qa.CO_2a + Qx.CO_2x}{Qv\ (1 - B) + Qx} \qquad \text{Eq 1}$$

ENGINE EXHAUST EMISSIONS

Assuming that a single 100 bhp indirect injection engine is operating at full load/speed in the underground workings, then typical engine parameters and undiluted exhaust constituent levels would result as follows:

CO_2x - 10%		power	100 bhp
COx - 250 ppm		fuel rate	50 lb/hr
NOx - 650 ppm		air rate	1000 lb/hr
NO_2x - 15 ppm		f/a ratio	0.05
SO_2x - 80 ppm		dry gas rate	987 lb/hr
RCDx - 60 mg/m^3		wet gas rate	1050 lb/hr

EXAMPLE RECIRCULATION CALCULATION

Exhaust Gas Flow and Ventilation Rate Determinations

For the sake of simplicity, it will be assumed that sufficient ventilation will be supplied to dilute the engine exhaust 100-fold. This will also permit easy checks for the calculated ambient concentrations resulting from dilution of the engine emissions.

The dry exhaust gas flow under standard conditions is:

$$Qx = 987\ \frac{lb}{hr} \times \frac{ft^3}{0.077\ lb} \times \frac{hr}{60\ min} = 214\ cfm$$

Therefore, the ventilation rate would be approximately 100 times Qx, or

$$Qv = 100 \times 1000 \frac{lb}{hr} \times \frac{ft^3}{0.075\ lb} \times \frac{hr}{60\ min} = 22{,}100\ cfm$$

This is the ventilation rate that would be supplied to the workings by the mine as a result of the application of a regulatory rule of thumb (X cfm/bhp), plus extra for a margin of safety. The above amount of air does indeed provide excess ventilation for the pollutants produced by the engine under the assumed operating conditions. Therefore, this leaves some possibility fo recirculation. This ventilation rate of 22,100 cfm is assumed to remain unchanged for these calculations.

Recirculation Calculations

Therefore, for 20% recirculation assumed:

$$Qr = 0.20 \times Qv = 0.20 \times 22{,}100 = 4{,}420\ cfm$$

$$Qa = Qv - Qr = 22{,}100 - 4{,}420 = 17{,}680\ cfm$$

As the CO_2 concentrations in fresh air is constant and known to be 0.035%, then Eq. 1 can be used to determine the CO_2o as follows:

$$CO_2o = \frac{Qa.CO_2a + Qx.CO_2x}{Qv\ (1-B) + Qx}$$

$$= \frac{17{,}680 \times 0.035 + 214 \times 10}{22{,}100\ (1 - 0.2) + 214} = 0.154\%$$

From a CO_2 balance, CO_2v can be calculated as follows:

$$Qa.CO_2a + Qr.CO_2r = Qv.CO_2v$$

therefore $$CO_2v = \frac{Qa.CO_2a + Qr.CO_2o}{Qv} \qquad \text{Eq 2}$$

$$= \frac{17{,}680 \times 0.035 + 4{,}420 \times 0.154}{22{,}100} = 0.059\%$$

and the contribution of the machine to the CO_2 concentration is:

$$CO_2o - CO_2v = 0.154 - 0.059 = 0.095\%$$

Similarly, the CO and other pollutant concentrations can be calculated for both the o and v stations using the form of Eqs. 1 and 2, as follows:

$$COo = \frac{Qa.COa + Qx.COx}{Qv\ (1 - B) + Qx} = \frac{17,680 \text{ X } 0 + 214 \text{ X } 250}{22,100\ (1 - 0.2) + 214}$$

$$= 0.012 \text{ X } COx = 2.99 \text{ ppm}$$

and $$COv = \frac{0 + 4,420 \text{ X } 2.99}{22,100} = 0.20 \text{ X } COo = 0.598 \text{ ppm}$$

and by similar calculations:

NOo = 7.80 ppm	SO_2o = 0.96 ppm
NOv = 1.56 ppm	SO_2v = 0.19 ppm
NO_2o = 0.18 ppm	RCDo = 0.72 mg/m³
NO_2v = 0.036 ppm	RCDv = 0.144 mg/m³

Using these ambient concentrations it is possible to calculate the AQI as follows:

<u>Air Quality Index Calculations</u>

$$AQI = \frac{CO}{50} + \frac{NO}{25} + \frac{RCD}{1.5} + 1.5\left[\frac{SO_2}{3} + \frac{RCD}{1.5}\right] + 1.2\left[\frac{NO_2}{3} + \frac{RCD}{1.5}\right]$$

$$AQIo = \frac{2.99}{50} + \frac{7.80}{25} + \frac{0.72}{1.5} + 1.5\left[\frac{0.96}{3} + \frac{0.72}{1.5}\right] + 1.2\left[\frac{0.18}{3} + \frac{0.72}{1.5}\right]$$

$$= 2.70$$

And, for reference purposes, the EQIx for 0% recirculation is:

$$EQIx = \frac{250}{50} + \frac{650}{25} + \frac{60}{1.5} + 1.5\left[\frac{80}{3} + \frac{60}{1.5}\right] + 1.2\left[\frac{15}{3} + \frac{60}{1.5}\right]$$

$$= 225$$

These calculations were repeated for 0% and 40% recirculation and the results tabulated below.

SUMMARY OF RECIRCULATION CALCULATIONS

Recirculation (%)	0				20			40		
Qa cfm	22,100				17,680			13,260		
Qr "	0				4,420			8,840		
Qv "	22,100				22,100			22,100		
Qx "	214				214			214		
Qt "	22,314				22,314			22,314		
CO_2a %	0.035				0.035			0.035		
location	x	v	t	net	v	t	net	v	t	net
CO_2 %	10	0.035	0.131	0.096	0.059	0.154	0.095	0.098	0.193	0.095
CO ppm	250	0	2.4	2.4	0.6	3.0	2.4	1.6	4.0	2.4
NO "	650	0	6.2	6.2	1.6	7.8	6.2	4.0	10.3	6.3
NO_2 "	15	0	0.14	0.14	0.04	0.18	0.14	0.10	0.24	0.14
SO_2 "	80	0	0.77	0.77	0.19	0.96	0.77	0.51	1.27	0.76
RCD mg/m^3	60	0	0.58	0.58	0.14	0.72	0.58	0.38	0.95	0.57
EQI	225	-	-	-	-	-	-	-	-	-
AQI	-	-	2.19	-	-	2.70	-	-	3.58	-

ANALYSIS OF RESULTS

Checks on the calculations include the unchanged "net" contributions of the engine-generated pollutants regardless of the recirculation rate, and the fact that the undiluted/ambient values approximate the 100:1 dilution ratio assumed.

The above results can be visualized by two plots: AQI vs % CO_2o and % CO_2o vs % recirculation. These are shown in Figures 1 and 2. Note that for and AQI limit of three the maximum permissible %CO_2o is 0.165%. This translates into a maximum allowable recirculation of 27%.

It should be noted that several assumptions have been made to complete this analysis, as follows:

(1) steady-state ventilation and engine operating conditions apply;

(2) full load/speed engine operating conditions pertain;

(3) recirculation of pollutants into the engine intake air does not change the concentrations of the pollutants emitted from the engine;

(4) no products of propane heater combustion have been included; and

(5) no amelioration (toxic constituent reduction) due to migration to mine walls (NO_2, SO_2 and soot), and no degradation due to conversion resulting from residence time (NO to NO_2) have been included.

CONCLUSION

This engine (Deutz F6L 912W) operating at full load/speed continuously in a ventilation stream of 22,100 cfm, produces pollutants which generate an AQI = 3 when 27% of the ventilation is recirculated.

For recirculation to be possible, excess ventilation (i.e. the AQI is less than 3) with no recirculation must be supplied. The 100:1 dilution ratio assumption provided this required excess ventilation for no recirculation in this case.

Measurement of the pollutants in the mine exhaust raise outlet and the subsequent calculation of the AQI would be a quick way to determine if recirculation would be a possibility in a given circumstance. This possibility can be estimated as follows:

$$\% \text{ recirculation possible} = \frac{\text{AQI max} - \text{AQI actual}}{\text{AQI max}} \times 100 \qquad \text{Eq 3}$$

$$= \left[(3.0 - 2.2) / 3.0 \right] \times 100 = 27\%$$

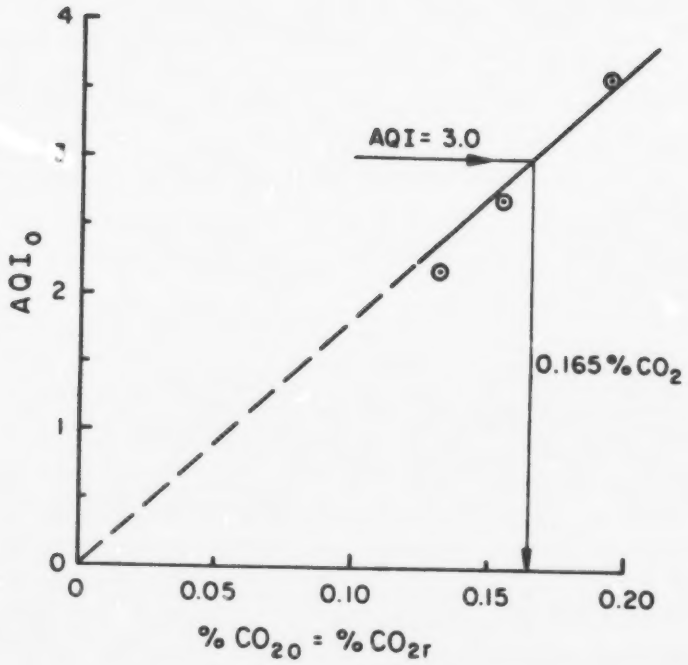


Fig. 2 AQIo vs CO2o

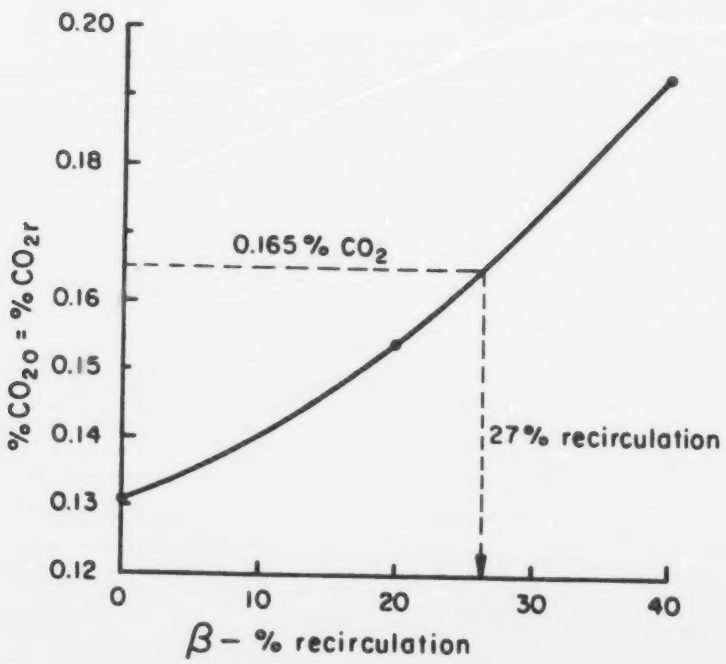


Fig. 3 - % CO2o vs % recirculation